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CHALLENGES IN DESIGN & DEVELOPMENT OF ENVELOPE MATERIALS FOR INFLATABLE SYSTEMS

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ABSTRACT

The state of the art material and technologies available for the flexible envelope materials for Inflatable systems have been emphasized in this paper. Inflatables such as Aerostats, Radome and Floats and their material property requirements have been discussed. The paper throws some light on the basis of selection of raw materials such as fabric substrate, coating polymer, grades of films for specific applications, based on their property mix. An overview of different sealing techniques used for fabrication of inflatable structures such as heat, RF, adhesive has been discussed along with coating and lamination techniques suitable for manufacturing such fabrics.

KEYWORDS: Coated Fabric, Interlamination Strength, Laminated Fabric, Lighter Than Air (LTA), Para-Aramid, Polyester, Tedlar®

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Original Article

INTRODUCTION

ADRDE is involved in development of number of inflatable structures viz., Aerostats, Emergency Floatation Systems for helicopters & Radomes which employs a wide range of textile materials as a major constituent. In such applications, textile materials usually operate under different dynamic loading conditions and undergo harsh environments with continual exposure to sunlight, temperature, water or moisture, etc., over long period of time.

The technology of basic materials for inflatable application has undergone continual advancement. The recent advances in the field of substrate materials, coating, lamination, polymer science & chemistry has broadened the range and versatility of the materials making it possible for a wiser selection of the same to suit the specific requirement of a system.

INFLATABLE SYSTEMS

Aerostat

An **aerostat** is a Lighter Than Air (LTA) craft (the average density of the craft is lower than the density of atmospheric air) that gains its lift through the use of a buoyant gas. Aerostats (Figure 1) include unpowered balloons and powered airships. A balloon may be free-flying or tethered. An aerostat's main component is one or more gasbags, a lightweight skin containing a lifting gas to provide buoyancy, to which other components such as a gondola containing equipment or people are attached. Aerostats are so named because they use aerostatic lift which is a buoyant force that does not require movement through the surrounding air mass. This contrasts with the heavy

aerodynes that primarily use aerodynamic lift which requires the movement of a wing surface through the surrounding air mass. The term has also been used in a narrower sense, to refer to the statically tethered balloon in contrast to the free-flying airship. Aerostats have both military as well as civil applications. Towards the military side, it is primarily used as a platform for surveillance, detection of low flying targets, tracking etc. Towards the civil side, it is used for radio and television broadcasting and environmental monitoring. The primary adjective of the aerostat is its easy maintenance and support. Although high performance aircraft radar systems provide excellent long-range detection of low-flying aircrafts and other targets but the limited on-station time and requirement of multiple aircraft and operating crew to provide round-the-clock coverage results in high acquisition and operation cost.

Figure 1: Aerostat System

Radome

A **Radome** (which is a portmanteau of radar and dome) is a structural, weatherproof enclosure that protects a microwave (e.g. radar) antenna. The radome is constructed of material that minimally attenuates the electromagnetic signal transmitted or received by the antenna. In other words, the radome is transparent to radar or radio waves. Radomes protect the antenna surfaces from weather and conceal antenna electronic equipment from public view. They also protect nearby personnel from being accidentally struck by quickly rotating antennas. Radomes (Figure 2) can be constructed in several shapes (spherical, geodesic, planar, etc.) depending upon the particular application using various flexible construction materials. A radome is often used to prevent dust, ice and freezing rain from accumulating directly onto the metal surface of antennas.

Figure 2: Hemi Spherical Radome

Radome is fabricated from strong and flexible rubberised airtight material supported by air pressure. Since the structure material is relatively thin and uniform, it approximates to thin shell structural membrane that provides very low transmission loss of electrical signal. An inflatable radome is constructed of gore shaped fabric sections with seams in the vertical direction. This is kept inflated through air blowers. Reliable operation depends on the use of uninterruptible power supplies and redundant air blowers. These structures can be folded into small package, which makes it suitable for transportable radome requiring mobility and quick assembly and disassembly time.

Emergency Flotation System

At ADRDE a number of Floatation Systems have been developed such as Emergency Floatation System (EFS) for helicopters (Figure 3), Floats for Space Capsule Recovery Experiment (Figure 4).

Figure 3: EFS for Helicopter

Figure 4: Float for Space Capsule Recovery

REQUIREMENTS OF ENVELOPE MATERIALS

Envelope materials used in the inflatable application should have the following properties:

- **High Strength:** The strength of the materials determines the maximum possible size of the LTA. The bigger is the diameter greater is the hoop stress, hence higher strength is the requirement.
- High strength to low mass ratio is required to maximize payload capacity.
- **Resistance to Environmental Degradation:** UV, temperature, humidity, etc. these factors are very important to determine the life of the Aerostat & its maintenance.
- **High tear Resistance to Prevent Catastrophic Failure:** Tear strength is one of the most important parameters for inflatable applications, since even a small tear can lead to catastrophic failure.
- Low gas permeability to minimize loss of filled gas. Higher Permeability of gas results in loss of operational capability & increased operational cost.
- Adequate seam joints capability is required to produce strong & reliable joints. They should not result in creep loss.
- Low creep to ensure that Aerostat shape is maintained throughout its life.
- Good abrasion & flexing resistance for handling.
- Ease of fabrication i.e. Radio frequency (RF), thermal, and adhesive sealability, etc.
- Low Electro Magnetic loss and high water repellency for radome application

A single fabric or film is unable to meet all the above characteristic requirements and therefore composite fabric structures are resorted to, for solving the problem. Normally, a woven fabric of nylon, polyester or Para Aramid (Kevlar) yarn forms the strength bearing member which is either coated with specific polymeric materials or laminated with particular films or even fabric with intermediate adhesive layers to obtain the required characteristics.

To meet the requirement, there are a few types of construction, generally found suitable for designing these materials which are shown in Figure. 5 viz.

- Single ply fabric with coating on both sides
- Single ply fabric with coating on one side and film on the other (using film transfer technique)
- Laminate of coated fabrics.
- Laminate of films and strength bearing fabric.
- Two ply fabric (woven & non-woven) with coating on both sides.

The comparative properties of these constructions are shown in Table 1.

Table 1: Properties of Various Configurations of Fabrics used for Inflatable Application

Construction	Gas Impermeability	Flex life	Tear Strength
A. Single ply fabric with coating on both sides	Good	Excellent	Poor
B. Single ply fabric with coating on one side and film on the other side	Very Good	Very Good	Poor
C. Laminate of coated fabrics	Very Good	Good	Excellent
D. Laminate of films and strength bearing fabric	Excellent	Poor	Very Good
E. Two ply fabric (woven & non-woven) with coating on both sides	Excellent	Good	Very Good

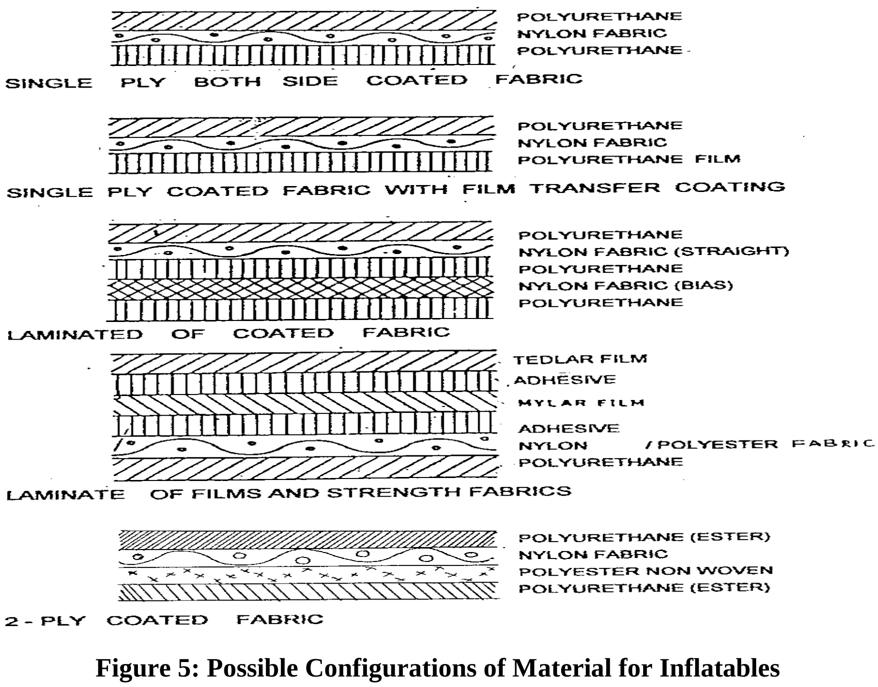

Figure 5: Possible Configurations of Material for Inflatables

MATERIAL SELECTION AS PER REQUIREMENT

The strength of the Inflatable envelope is dependent not only on the strength of the material but on the design and strength of its seams and accessories, as well as the procedures for fabrication, packing and final assembly. The current methods of envelope fabrication consists of Sealing the Fabric using radio frequency sealing machine, gluing, heat sealing, etc.

Essentially, the envelope material has to be a laminate of fabric and films similar to as given in Figure 6:

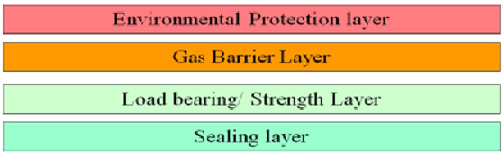

Figure 6: Broad Configuration of Envelope Material

Load Bearing/Strength Layer

There are various textile fibres that can be converted into suitable fabric that in turn can be used as load bearing/strength layer. The potential fibres are:

Nylon: Nylon (Polyamide) exhibits fair properties in terms of strength to mass ratio, good elastic recovery, excellent flex resistance, etc.

Polyester: Polyester is more or less similar as nylon except for UV resistance and elastic recovery property. UV resistance is better and elastic recovery is inferior to nylon.

Aramid: Para-aramid from DuPont (Kevlar®) has brought a quantum jump in strength to mass ratio along with a high thermal resistance. The poor resistance to photo-degradation, poor flexibility and crease resistance is still a matter of concern however, that can be taken care in subsequent coating/laminations. A product from Teijin named Technora® made of para/meta aramid claims greater chemical, elongation and abrasion properties and lower moisture gain over Para-aramid.

Vectran: Aromatic polyester Vectran™ is a high-performance multifilament yarn spun from liquid crystal polymer (LCP). Vectran fiber exhibits exceptional strength and rigidity. It has superior flex property over Kevlar.

Zylon (PBO): poly(p-phenylene-2,6-benzobisoxazole) is a trademarked name for a range of thermoset liquid crystalline polyoxazole. It also exhibits exceptional strength and rigidity, higher than any commercially available fibres. It is 60% stronger than Vectran in specific strength.

M5 fibre: polyhydroquinone-diimidazopyridine is a high-strength synthetic fiber first developed by Dr. Doetze Sikkema and his team at the Dutch chemical firm Akzo Nobel. Currently, it is being produced by the United States Magellan chemical company. M5 is stronger than Aramid (Kevlar, Twaron) and UHMWPE (Dyneema, Spectra).

Gas Barrier Layer

Polyurethanes (PU): These elastomers are excellent material for high performance coated fabrics. They have very good gas retention properties, environmental degradation resistance and also RF sealability.

Polyester Film: This film has excellent gas retention properties. In addition, its high tensile and shear strength makes it potential candidate for high performance laminates.

EVOH film: EVOH (Ethylene Vinyl Alcohol Copolymer) has outstanding gas barrier properties with excellent resistance to odour & flavour permeance. Outstanding gas barrier property makes this film as one of the most suitable member for gas barrier layer.

Aluminised Polyester: Coating of Aluminium on polyester further enhances the barrier property. Moreover, it provides extra protection against UV degradation of gas barrier film.

A comparison of potential gas barrier films is given in Table 2.

Table 2: Comparative Properties of Gas Barrier Materials

Material	Gas Permeability	Adhesion to Fabrics/Films
Polyurethane	Low	Excellent
Polyvinyl fluoride	Low	Poor
Polyester	Low	Fair
Nylon	Very Low	Fair
PVDC Copolymer (Saran)	Very Low	Fair
PTFE (Teflon)	Fair	Poor
PVC	Fair-low	Excellent

Environmental Protection Layer

Tedlar (Poly Vinyl Fluoride) Film: It has got excellent UV resistance along with moderate physical and gas retention properties. This makes it an excellent member as the outermost layer in laminated fabric construction.

Teflon: Teflon (poly vinyl tetra fluoride) is one of the inert materials. It has all the good properties of PVF, however being dense, is inferior for Airship applications.

Aluminised Tedlar: Coating of Aluminium on PVF further enhances the barrier property. Moreover, it provides extra UV protection to inner layers.

Kapton: It is a polyimide film developed by DuPont which can remain stable in a wide range of temperatures, from -273°C to +400 °C It is used in, among other things, flexible printed circuits (flexible electronics) and thermal micrometeoroid garments, the outside layer of space suits.

Polyurethanes (PU): These elastomers have good environmental degradation resistance and also RF sealability. Aliphatic ester grade of PU has been used as environmental barrier in present PU coated fabrics for Aerostats at ADRDE. This fabric has limited life and studies are being conducted to enhance its usage life.

A comparison of environmental protective films is given in Table 3:

Table 3: Comparative Properties of Environmental Protective Materials

Material	Heat Sealable	Weatherability	Flex-Fatigue Resistance	Dimensional Stability
Polyurethane	Yes	Good	Good	Poor
Polyvinyl fluoride	Yes (with adhesive)	Excellent	Excellent	Good
Polyester	No	Fair	Fair	Excellent
Nylon	-	Poor	Excellent	Excellent
PVDC Copolymer (Saran)	Yes	Poor	Fair	Good
PTFE (Teflon)	Yes (some grades only)	Excellent	Good	Good
PVC	Yes	Good	Good	Poor

Adhesive/Sealing Layer

Polyurethanes (PU): These elastomers are excellent material as adhesives and as sealing layer.

Acrylic adhesives: Special acrylic adhesives are used to laminate the gas barrier layer and environmental protection layer as PVF is relatively inert material.

Coating Materials

PVC Coating

Polyvinyl chloride (PVC) is one of the few synthetic polymers which has found wide industrial application. For processing and imparting properties for special applications, PVC is compounded with a variety of additives. Some of the important additives are as follows:

- **Plasticizers:** Plasticizers are an important additive of PVC resin, because the majority of PVC products are plasticized. These are liquids of low or negligible volatility or low molecular weight solids, which when incorporated into the polymer improve its process ability and impart to the end product softness, flexibility, and extensibility. The other concomitant effects of plasticization are lowering of *T*g and softening temperature, reduction of strength, and increased impact resistance. The plasticizers used in PVC coating may be Phthalates, Phosphates, Aliphatic diesters, Epoxies Polymeric plasticizers types.

- **Heat Stabilizers:** Unless suitably protected, PVC undergoes degradation at the processing temperatures and by heat and light. The manifestation of the degradation are the evolution of hydrogen chloride, development of color from light yellow to reddish brown, and deterioration of mechanical properties. PVC also undergoes photodegradation on exposure to light in the presence as well as in the absence of oxygen. In plasticized PVC, exudation of plasticizers from PVC occurs on weathering, which has been attributed to their partial exclusion from the areas where cross-linking has occurred.

- **Fillers:** The primary role of a filler in PVC is reduction in cost, but they can play a functional role by improved processing, and desired properties of the end product. The common fillers are calcium carbonate fillers (whiting, marble dust), silicates (clay, talc, and asbestos), and barytes.

- **Lubricants:** The role of a lubricant is to facilitate processing and control the processing rate. Mineral oil, silicone oils, vegetable oils, and waxes are common lubricants. Metal stearates of Pb, Ba, Cd, and Ca may be used for the dual purpose of stabilizing and lubricating. The compatibility of lubricants is low, resulting in their exudation at processing conditions

- **Colorants:** The colorants of PVC are inorganic and organic pigments. The inorganic pigments include titanium dioxide, chromium oxide, ultramarine blue, and molybdate orange. The organic pigments are phthalocyanines, quinacridines, and benzidines. The inorganic pigments have excellent heat resistance, light stability, and opacity.

- **Flame Retardants:** The inherent flame retardant property of PVC due to the presence of a chlorine atom is affected by the addition of flammable plasticizers. Antimony trioxide and borates of zinc and barium are widely used for the purpose. Chlorinated paraffins and phosphate ester plasticizers also act as flame retardants.

- **Plastisols and Organosols:** Plastisols and organosols are fluids in which fine PVC particles are dispersed in plasticizers. Plastisol or pastes (used synonymously) do not contain any solvent or volatile component. The viscosity of plastisols varies from pourable liquids to heavy pastes. PVC pastes have two important characteristics:

  - They are liquids and can be processed in that condition. The processing conditions are determined by the property of the paste at ambient temperature.

- On application of heat, when required, they fuse to viscous solutions of polymer in plasticizer, and on cooling result in familiar plasticized PVC.

A typical formulation consists of resin, plasticizer, stabilizer, fillers, pigments, and viscosity modifiers. Unlike solid formulations, lubricants and polymeric modifiers are not added in pastes.

An organosol is a plastisol containing volatile organic solvent. Diluents (organic solvents) are added to reduce the viscosity of plastisols, to make them suitable for spray, roller, brush, and other forms of coatings. The diluents are nonsolvents of PVC, like toluene, xylene, naphtha, and mineral spirits. The addition of diluents shifts the solubility parameter of the dispersing medium away from PVC, lowering the solvation and reducing the viscosity. As the diluent level increases, the viscosity passes through a minima and then increases with further dilution. This increase of viscosity is due to flocculation of the plastisol resin.

Polyurethane Coating

Polyurethanes are polyaddition products of di- or polyisocyanate with a dior polyfunctional alcohol (polyol). The two important building blocks are the isocyanates and polyols. Chain extenders like short-chain diols or diamines, and catalysts are frequently used in the synthesis of the polymer.

Cross-linkers and chain extenders are low molecular weight polyfunctional alcohols and amines that act as chain extenders or cross-linkers by reaction with an –NCO group. The alcohols form urethane, and the amines form urea linkages. The difunctional compounds are essentially chain extenders, and the compounds with functionality greater than two are cross-linkers. The end properties of the polyurethanes are considerably influenced by these compounds as they alter the hard to soft segments proportion of the polymer.

Polyurethanes prepared from short-chain diols and diisocyanate have a large concentration of urethane linkage which results in a high degree of hydrogen bonding between the –NH and C=O groups of the chains. Consequently, these polymers are hard and have a low degree of solubility. On the other hand, the reaction product of long-chain polyols and diisocyanates results in polymers with a low concentration of urethane groups. The intermolecular forces are, therefore, mainly weak van der Waal’s forces, and the polyurethane is low in hardness and strength. Most polyurethanes are prepared from at least three basic starting materials: long-chain polyols, diisocyanate, and a chain extender.

Thermoplastic urethane elastomers (TPUs) are high molecular weight polymers obtained by the reaction of polyol, diisocyanate, and chain extender.

The conventional solution-based coatings are of two types: one-component systems and two-component systems.

- **One-Component Systems**

  There are two types of reactive and completely reacted systems:

  - Reactive one-component systems: These systems are low molecular weight prepolymers with terminal isocyanate groups. They are dissolved in solvents of low polarity. After coating, they are moisture cured. The water acts as a chain extender and cross-linking agent with the formation of urea and biuret linkages. The generation of carbon dioxide is sufficiently slow, so that slow diffusion of the gas from the film occurs without bubble formation. The rate of cure is dependent on the temperature of the cure and humidity of the

ambient. The use of blocked isocyanate prepolymers allows for formulations of a one-component system stable at room temperature.

- Completely reacted one-component systems: These consist of totally reacted high molecular weight, thermoplastic polyurethane (PU) elastomer. The PU is dissolved in a highly polar solvent like dimethyl formamide. These coatings dry physically.

- **Two-Component Systems**

In this type of coating system, isocyanate-terminated prepolymers or polyfunctional isocyanates are reacted with polyhydroxy compounds that may already be urethane modified. The polyisocyanate component, usually in the form of a solution, is mixed with the polyhydroxy component just prior to coating. Curing of these coatings occurs due to the formation of urethane linkages. In addition, reaction with moisture takes place.

In the U.S., for PU-coated fabrics, TPU systems are preferred. By varying the polyol and NCO/OH ratio in the TPU manufacturing process, the same wide range of flexibility can be obtained as mentioned for the two-component systems. The proper choice of adhesive for the TPU layer is critical. It is common practice to add a polymeric isocyanate to the TPU layer to aid in adhesion to the base fabric. Solvent-free coatings by TPU elastomers can be obtained on the fabric by the hot-melt process of the solid polymer. The common method employed is the Zimmer coating method.

COATING METHODS

Coated Fabric

A coated fabric is textile fabric on which there has been formed in situ, on one or both surfaces, a layer or layers of adhered coating materials. A range of coating methods is available for application of polymeric materials to the substrate. Only three commonly used methods for specific application are furnished below:

Solution Coating Method

Solution coating is generally accomplished by knife coating techniques. There are two such techniques viz. floating knife and knife over roll technique. The tie coat is made by floating knife technique, which provides better penetration into the substrate and hence improves adhesion of coating to the substrate. Another technique, i.e., knife over roll gives more uniform coat and hence it is used for the subsequent coats.

Melt Extrusion Coating (Zimmer Coating)

Knife coating technique has a tendency to develop pin holes and make potential sources of leakage. However, Zimmer coat provides a film-like coating and hence provides better gas retention property but Zimmer coats less than 100 gsm is not uniform. This type of coating is used for coating polyurethane on the gas side of the fabric intended for inflatables.

LAMINATION METHOD

Laminated textiles consist of one or more layers of textile and films. The Textile Institute defines a laminated or combined fabric as; ‘a material composed of two or more layers, at least one of which is a textile fabric, bonded closely together by means of an added adhesive, or by the adhesive properties of one or more of the component layers’. A range of lamination methods is available for application of polymeric materials to the substrate as furnished below:

Adhesive Lamination

The adhesive is required to bond the fabric/film and component layers together. Creating a strong bond, which will not deteriorate through conditions experienced during usage, is an ideal goal. Adhesives are often associated with making the fabric too rigid and thus affecting the handle, which is often a negative characteristic, particularly for applications in performance clothing where comfort is a requirement. Environmental consideration has led towards more interest in hot melt adhesives, rather than solvent based adhesive, or the use of flame adhesion. Based on the lamination of film, adhesive lamination is of two type viz. Wet Lamination & Dry Lamination.

Flame Lamination

This technique is mainly used to attach foam to a textile fabric, which is widely used in automotives. The foam is presented to the flame, which encourages melting; as it dries it bonds the textiles. This technique has associated health and safety risks due to the release of gases when melting takes place.

Hot Melt Lamination

It is the state-of-the-art process. It uses reactive or hot-melt adhesive which is applied onto surfaces to be bonded with an engraved roller. This allows for perfectly even adhesive distribution and such a laminate is not subjected to any heat treatment.

There are two processes involved in hot melt lamination, the application of a thermo-set adhesive, and the fusing of the fabric and the non-textile component through heat and pressure. Adhesive is applied either to the whole surface, or discreet, where the adhesive is applied as a thermo-set, which just attaches in patterns, such as glue dots. Discreet provides greater flexibility due to the reduced contact areas.

LATEST TRENDS FOR THE DEVELOPMENT OF ENVELOPE FABRIC

The status of development of various coated /laminated fabrics are given below:

Base Fabric

A number of base fabrics for coated fabrics in plain, MAT, three end leno weave, warp inserted weft knitted configurations have been developed for various applications such as Aerostat, Radome, Floats, etc. The different types of polymers used are polyester, nylon, Kevlar & Vectran.

Coated Fabrics

In the recent past ADRDE has successfully developed various high performance coated fabrics for different systems viz Balloon Barrage System for passive air defence, Aerostat for surveillance, 1000 kg payload recovery, emergency landing system on Sea for Helicopters, Floatation system for stability of Seaking Helicopter during emergency landing on sea, Flotation system for Space Payload Recovery, Hemi spherical dome structure for shelter of Radar, etc. These fabrics include PU, PVC, Neoprene and Butyl coatings on Nylon, PET, Para Aramid fabrics & Vectran. For 2000 cu. m Aersotat the material used for envelope is PU coated nylon fabric having 250 kg/5cm strength and weight is 360±25 gsm.

Improved Coated Fabrics through Incorporation of Nano Fillers

The dawn of nanotechnology has dramatically improved material properties in engineering plastics, polymer products, rubber, adhesives and coatings. Intercalation of polymers in layered silicate clay hosts has proved to be a successful approach to synthesize nanophase organic and inorganic hybrid Nanocomposites. The benefits of such clay loading are improved mechanical (Tensile), dimensional, gas barrier, thermal stability and flame retardancy properties at very low loadings of the nanoclay. Keeping this in view, a feasibility study was conducted to improve the properties of PU coated nylon fabric by dispersing nanoclay in the polymer matrix. The study at lab level revealed that the hydrogen permeability of coated fabric having coating thickness of 0.25mm is 1.38 lit/sq.m/day for no clay and 0.88 lit/sq.m/day for 3% nanocomposite. As a spin off benefit, the nanocomposite-coated fabric shows better mechanical properties like breaking force, elongation at break, tearing strength etc. and improved thermal property.

Improved Coated Fabrics through Incorporation of UV Additives & Carbon Black

In order to enhance usage life of the coated fabric UV additives viz. UV stabilizer, light stabilizer & anti oxidant and Carbon black have been added in coated and laminated fabrics.

Top Finish of Poly Vinylidene Fluoride (PVDF) on Coated Fabric

Inflatable system such as Radome has been continuous exposed to the outdoor environment. The fabric used in this system is the PVC Coated Polyester fabric. Due to continuous exposure of the fabric in the outdoor environment, the plasticizer of the PVC coating leaching out & makes dust & dirt to stick on it, which also causes the degradation of fabric. A thin coat of Poly vinylidene fluoride (PVDF) on PVC Coated Fabric applied as top finished significantly enhances the life of the PVC Coated Fabric. More importantly, it helps in keeping the structure self cleaning, i.e. it does not let dirt and dust settle on the fabric easily which is a common feature with PVC coated fabrics since plasticizers of PVC leaches out on which the dirt sticks. But the application of thin layer of PVDF coating is not an easy task as this was affect the sealability of the fabric which is the main requirement. After lots of trials suitable grade of PVDF is selected which does not affect the sealability of the fabric.

Laminated Fabric

Tedlar® Polyester film based Laminated Fabric, is better than existing PU coated fabric in terms of:

- Better gas permeability.
- Desired strength in lower mass.
- Enhanced life.

Besides the above advantage, laminated fabric has got one limitation as compare to PU coated with respect to flexibility, hence this fabric is preferred where the packing & unpacking requirement is lesser.

Adhesive for Lamination: There are innumerous adhesives available in the market. Therefore it is important to shortlist adhesives based on the envelope requirement, environment of envelope, surface chemistry, application techniques, etc. A number of solvent based polyurethane and acrylic based adhesives are found suitable for such applications.

Lamination Process Parameters

After selection of appropriate adhesive, the lamination parameters need to be optimized to get the desirable interlamination strength. The various lamination process parameters optimized are mentioned below:

1. Drying Time	2. Drying Temperature	3. Curing Time
4. Curing Temperature	5. Nipping Pressure	6. Nip Zone Temperature
7. Speed of machine	8. Type of roller used for nipping	9. Type of knife
10. Knife setting in adhesive lamination	11. Openness of roller in hot melt lamination	12. Pressure on winding & unwinding roller

Enhancement of Interlamination Strength between Films

The interlamination strength between layers depends on surface tension of film & adhesive, proper selection of adhesive & optimization of lamination parameters w.r.t. adhesive, temperature and time of curing, cooling, etc.

As per the literature, the critical surface tension of the films to be laminated should be higher than the surface tension of the adhesive. Polyvinyl fluoride (PVF) film, available as Tedlar® from Dupont, being slightly inert in nature has got the critical surface tension ~30 dynes/cm. Hence it was not easily adherable with commonly available adhesives having surface tension of 40 dynes/cm. The critical surface tension of control PVF film was increased to 44-48 dynes/cm after corona treatment. The adhesion between PET film and PVF film has increased significantly after application of corona treatment.

SEALING TECHNIQUES/ METHODS FOR FABRICATION

The strength of the inflatable envelope is dependent not only on the strength of the material but on the design and strength of its seams and accessories, as well as the procedures for fabrication, packing and final assembly. The various sealing techniques available are:

- Radio Frequency (RF) sealing
- Adhesive Sealing
- Impulse heat sealing

Radio Frequency (RF) Sealing

Radio Frequency Welding is the process by which electromagnetic energy is used to permanently bond thermoplastic materials together. This is different than other processes as the desired result is a hermetic, cohesive bond between the polymers. This type of welding can only occur between highly dipolar materials that are excited by an alternating magnetic field. Dielectrics is an established leader in thermoplastic welding for the medical device industry, and best known for our expertise in Radio Frequency Welding (also referred to as "RF welding", "Dielectric sealing", "High frequency" welding, or "heat sealing"). The RF Welding process uses radio frequency energy to produce molecular agitation in thermoplastic materials (e.g. thermoplastic polyurethane, PVC, PVDC, EVA, PET, nylon and other customized resins) such that they melt and flow together, forming a bond that is as strong as the original materials.

During welding, components are clamped under pressure between machined electrodes. A magnetic field is generated between the electrodes, passing through the components, fusing the material together.

Adhesive Sealing

In Adhesive sealing process adhesive is used to bond the two surface. The adhesive should be well homogeneously mixed with appropriate percentage of accelerator. The mixed adhesive should be applied 3 liberal coats to the surface to be bonded allowing 20 minutes drying time after each coat. The mass of each coat is 15–20 gsm. After application of the last coat, 15 min. should be given to dry the coated adhesive. This will be followed by either Heat Activation or Solvent & curing.

Heat Activation: Using an infrared or heat sources, both adhesive coated surfaces should be heated upto 71°C & combined immediately followed by proper rolling for full contact.

Solvent Activation: After the drying of the last coat, swab one surface of the adhesive film with MEK (Ethyl acetate may also be used). Allow the excess solvent to flash off (~30 seconds). Join the surfaces and apply pressure with hand roller for a few minutes.

Curing: The joint should be kept for 7 days at Room Temperature. This is a chemically curing system. After adhesive coating, the heat activated dry adhesive film should be matted as quickly as possible.

Impulse Heat Sealing

Impulse welding is the process by which electricity is used to generate heat through a high resistance wire/plate. The wire/plate is typically nickel-chromium encapsulated in a non-stick coating. A current will cause the plate to heat up rapidly that is transferred to the materials which under specific pressure leads to fusion between two or more layers.

CONCLUSIONS

Selection of proper polymeric materials, fabric & fabrication technology plays an important role in design & development of Inflatable System.

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